A Population Dynamics Model of the Vector of Chagas' Disease

by

Patricia Himschoot

and

Jorge Rabinovich

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ABSTRACT

A simulation model was developed to represent the population dynamics of two bugs (*Triatoma infestans* and *Rhodnius prolixus)* the main vectors of Chagas' Disease. The model includes the infection process of bugs with the parasite causing the disease (*Trypanosoma cruzi*). Human and animal hosts for bugs were considered; bug migration between houses and the wild environment was also modeled; the three types of houses most common in rural areas were considered. The bugs' population regulation mechanisms were modeling acting over mortality and natality.
Populations of both species showed sustained oscillations under certain conditions, proportional to the length of each species' development time. The symmetry of the fluctuation seems to be affected by female fecundity. Sensitivity analyses show that the main parameters affecting the stability behavior of the vector population were: a) female fecundity, b) number of hosts available, c) the threshold nymphal density at which irritation of the hosts starts, and d) the emigration rate. The threshold nymphal density at which irritation of the hosts starts combined with female fecundity, provided critical in producing a change in the stability behavior of the population, from a stable equilibrium to a limit cycle.

A population dynamics simulation model of the vector of Chagas' Disease.

Himschoot Patricia[(1)]
and Jorge Rabinovich[(2)].

(1) Biometrics Unit, Cornell University.
(2) University of Buenos Aires, Argentina.

INTRODUCTION.

Chagas' Disease is one of the most serious current health problems in Latin America, affecting about 16 to 18 million of people.

The disease

Chagas' Disease is caused by a parasite (*Trypanosoma cruzi*) which is transmitted by an bloodsucking insect vector of Triatominae familie affecting as domestic and wild animals and humans. The parasite, during a state of its life lives in the blood or/and tissues and the intercellular habit of any vertebrate class, and in another states in the invertebrate hematophage's intestine.

The transmission is produced when the bugs feed and often defecate on the skin of their host. Their feces with parasites entry into the body of the vertebrate host through the bite producing damage in the heart, digestive and nervous system.

Principal problems in its control:

-Ecological characteristics of the insect vector.
- Complex socio-economic aspects of the human population at risk (related with the primary dwelling in which live the rural population in Latin America).

THE MODEL

Spatial unit: the human dwelling.

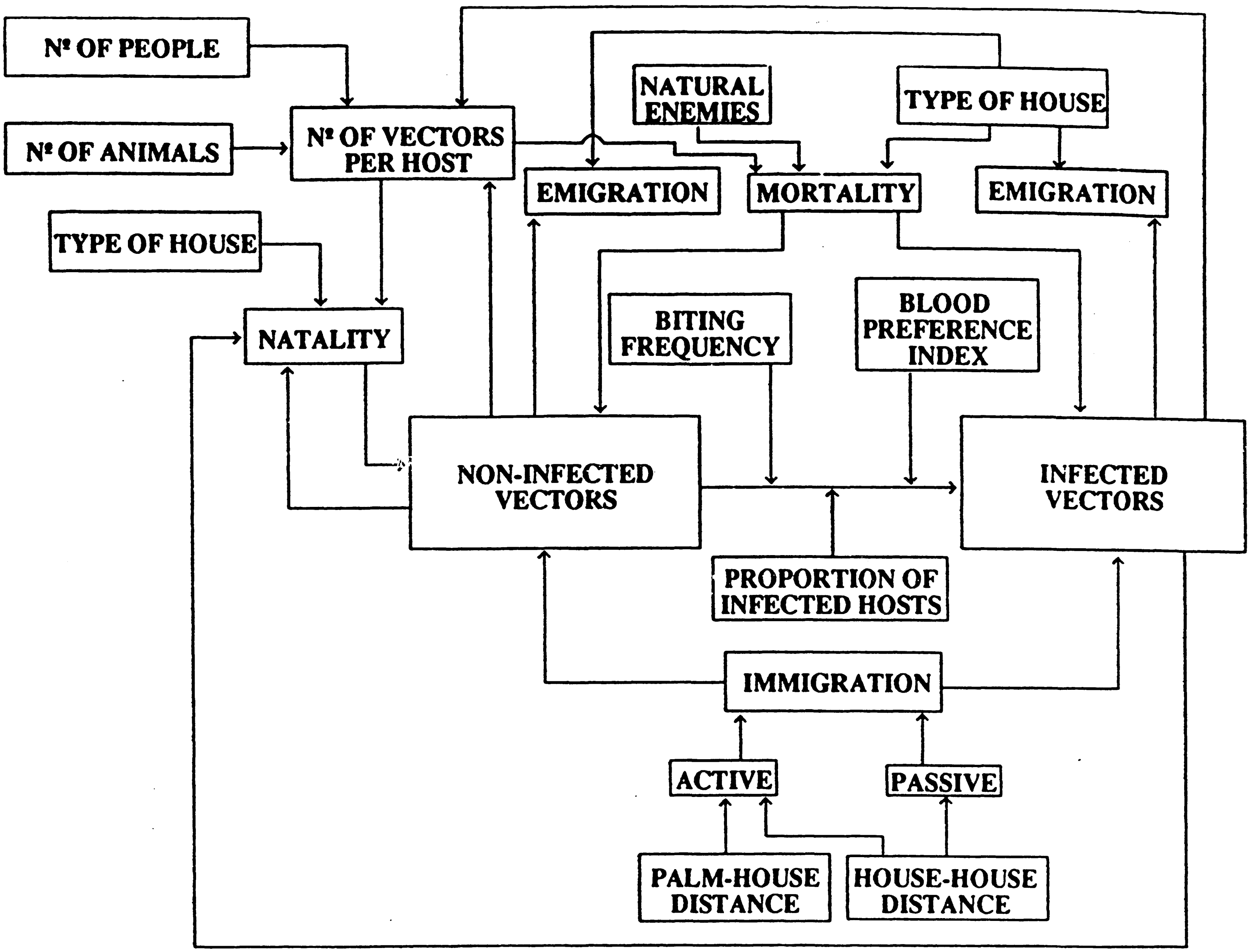
Time unit: one day.

Species considered: *Triatoma infestans and Rhodnius prolixus.*

Types of houses considered:

Type 1: typical shack of mud walls and palm or branch roof.
Type 2: mud walls and tin roof.
Type 3: dwelling built of bricks and cement.

As the bugs hide in the roof and wall cracks the number of refuge available decreases from type 1 to 3. The vector carrying-capacity of each type of house is related to the amount and kind of refuge available.

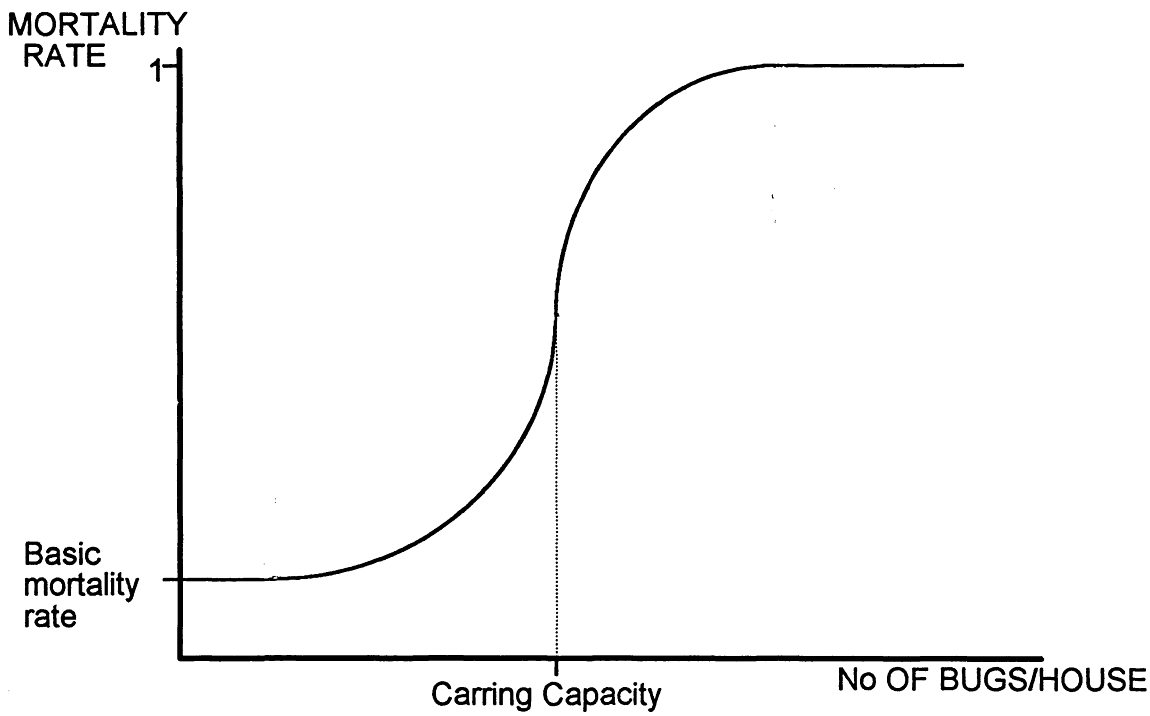


Nº OF PEOPLE
Nº OF ANIMALS
Nº OF VECTORS PER HOST
TYPE OF HOUSE
NATALITY
NATURAL ENEMIES
TYPE OF HOUSE
EMIGRATION
MORTALITY
EMIGRATION
BITING FREQUENCY
BLOOD PREFERENCE INDEX
NON-INFECTED VECTORS
INFECTED VECTORS
PROPORTION OF INFECTED HOSTS
IMMIGRATION
ACTIVE
PASSIVE
PALM-HOUSE DISTANCE
HOUSE-HOUSE DISTANCE

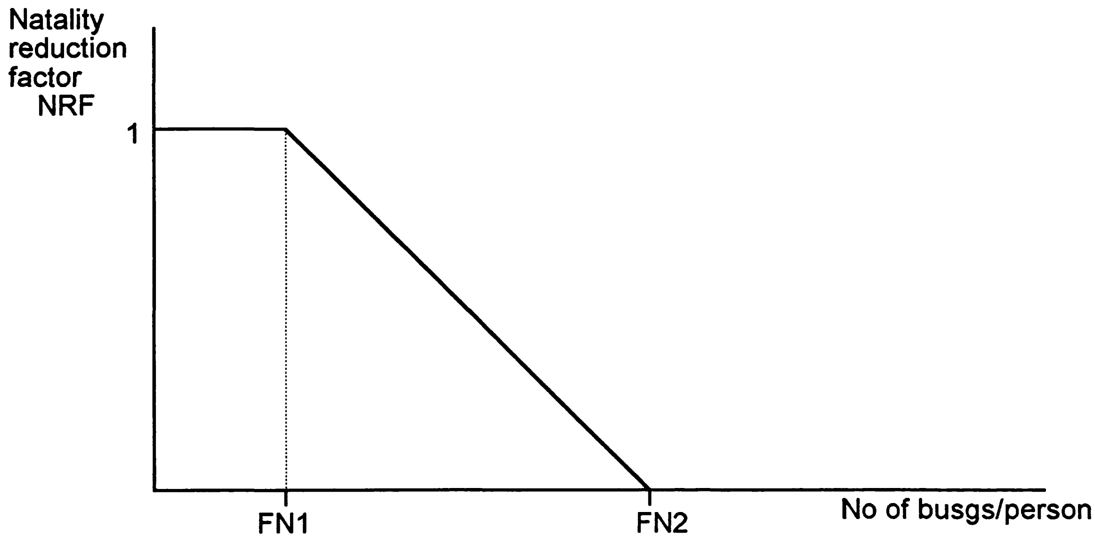
Process	Function	Parameter or variable	
Development time	DT=EDT+NDT	DT	Time from egg laid to mature female
		EDT	Time from egg laid to egg hatched
		NDT	Time from egg hatched to mature female
Fecundity	NH=FEC*FN*VA*PH	FN	Natality reduction factor related with irritability
		FN1	Threshold density at which irritability starts
	FN=(FN2-(D/AL))/ (FN2-FN1)	FN2	Density at which reproduction stops
		PH	Sex ratio(female/adult)
		D	Density
		AL	Food sources
		NH	N. of eggs laid
		FEC	Natality rate
		VA	Adult population
Hatching	$NNE=NH*(1-EM)^{EDT}$	NNE	No. eggs producing nymphs
		EM	Daily egg mortality

Process	Function	Parameter or variable	
Natural mortality	$MN=MB+(1-MB)/(1+(K_j/D)^{20})$	MN	Mortality rate
		MB	Basic mortality rate
		K_j	Carring capacity
		j	House type
Starvation mortality	TM=(FS2- (D/AL))/(FS2 - FS1)	TM	Starvation mortality rate
		FS1	Threshold density at which irritation starts
		FS2	Density at which there is no survival
Migration	NI=(D*TE*FR)+(FV*PC/360)+IP	NI	No. of immigrating adults
		TE	House emigration rate
	NE=D*TE	FR	Fraction of immigrats that return
		FV	No of bugs per visit
		PC	Social visiting rate
		IP	Palm emigration rate
		NE	No. of emigrating adults
Vector infection	PI=PP*PAR*FP/AL	PI	Proporortion of new infected bugs
		PP	Bug infection probability
		PAR	No. of infected hosts
		FP	Biting rate

Natural and predation mortality rate

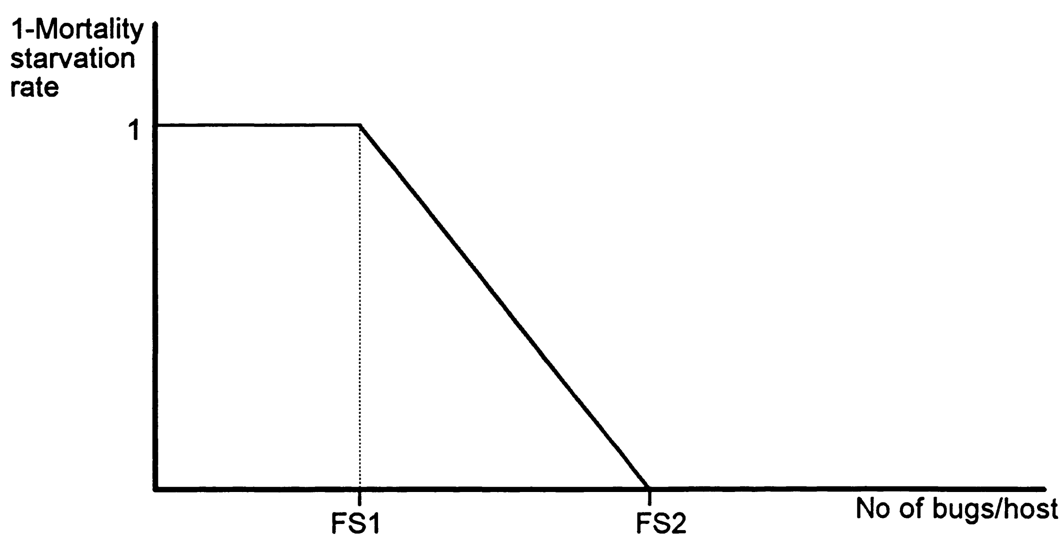


Functions related with the irritability of the hosts



NRF = (FN2 - No of bugs/host) / (FN2 - FN1)

NE = FEC * NRF* No of female adults



Vector's population-density regulation mechanism.

This mechanism is a food-limited process but responds to accessibility of the host and not to their numbers (Schofield, 1980, 1982, Weir-Lopez, 1982; Rossell, 1984). The higher number of insect bites per person per night, the higher the irritation produced to the human and animal host. Due to this irritation, and the victims' response to it, bug's blood ingestion is interrupted, producing:

a) a reduction in fecundity (fewer eggs per female per day);

b) an increase in mortality due to higher predation by natural enemies, associated with a higher number of feeding attempts;

c) an increase in mortality due to starvation.

RESULTS

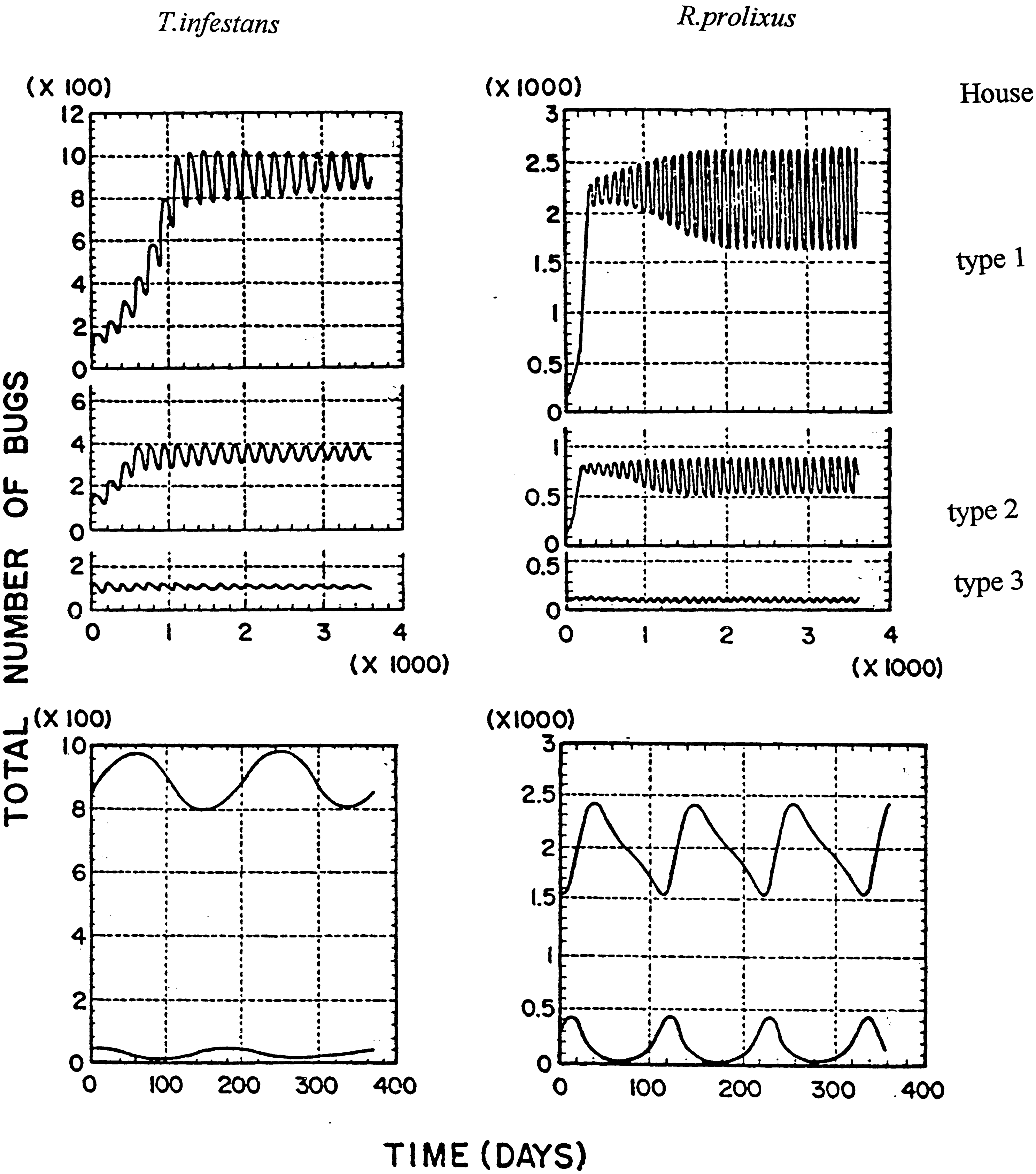
1) The effects of the initial conditions upon the final stable results proved to be unimportant.

2) Effects of different house types.

3) Both species display sustained oscillations.

4) During the oscillations the population development stage pyramid changes. Adults represent a small fraction of the total population (2% and 5%).

5) The bug population's infection fluctuates, oscillating between 30% and 60% for *T.infestans* and 5% and 20% for *R.prolixus.*



T.infestans
R.prolixus
House
type 1
type 2
type 3
(X 100)
(X 1000)
(X 1000)
(X 1000)
(X 100)
(X1000)
TOTAL NUMBER OF BUGS
TIME (DAYS)

SENSITIVITY ANALYSIS

The vector average population and its standard deviation were calculated by averaging the daily total population of vector's per year and then computing the mean of means and its standard deviation for the last ten years of simulating.

In all the cases the coefficient of variation jumps from null values to relatively high ones, suggesting a change in the stability behavior from stable point to a limit cycle.

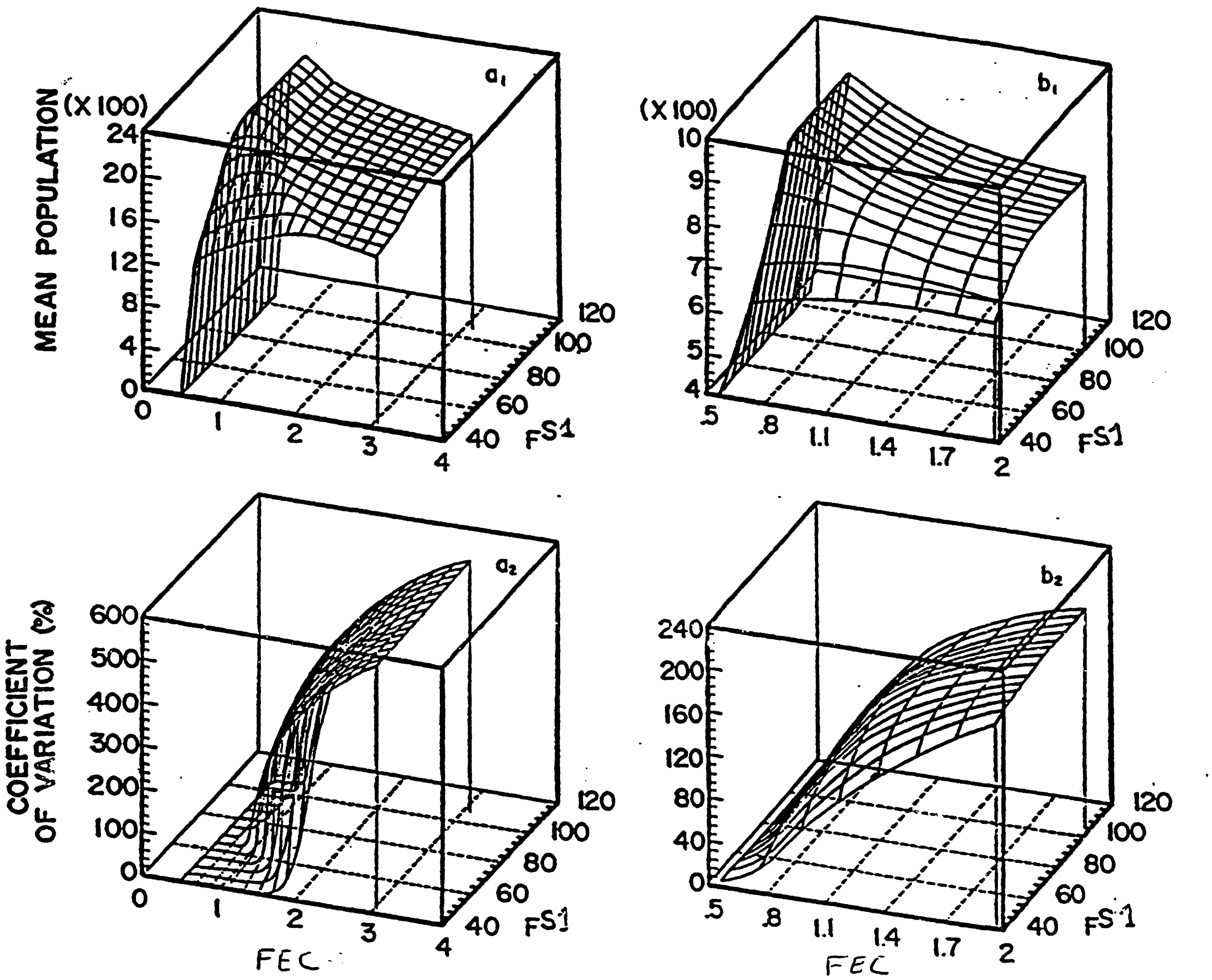
CONCLUSION

- The population of both insect species fluctuate with periodicities that reflect their development times: *R.prolixus* with 90 days of total development time has about four peaks per year and *T.infestans* with 170 days has about 2 cycles per year.

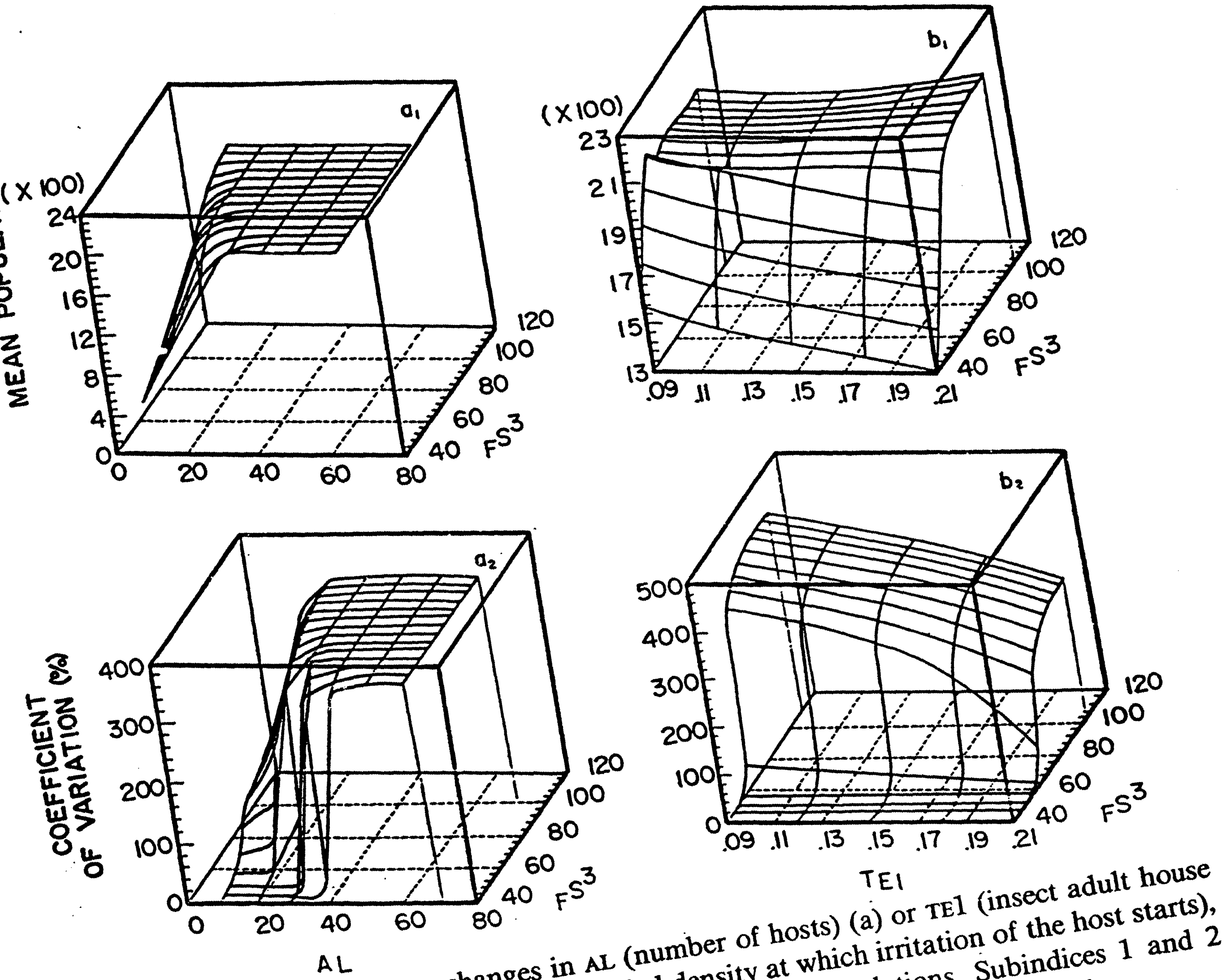
- The peak of the adult population lags behind the nymphs peaks in proportion to the developmental time of each species.

- The asymmetry of the population oscillation seems to be related to fecundity.

- The densities of the simulated populations show two types of behavior according with the values of some parameters:equilibrium point or limit cycle. The oscillations are product of the non-linear mortality and the values of the fecundity and the development time.



. Effect of simultaneous changes in FEC (natility rate) and FS1 (threshold nymphal density at which irritation of the host starts) on the stability behavior of simulated *Rhodnius prolixus* (a) and *Triatoma infestans* (b) populations. Subindices 1 and 2 represent the average stable population and its coefficient of variation, respectively.



. Effect of simultaneous changes in AL (number of hosts) (a) or TE1 (insect adult house emigration rate) (b) and FS3 (threshold nymphal density at which irritation of the host starts), on the stability behavior of simulated *Rhodnius prolixus* populations. Subindices 1 and 2 represent the average stable population and its coefficient of variation, respectively.